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Stochastic transport in an idealized ocean-atmosphere coupled system

Long Li¹

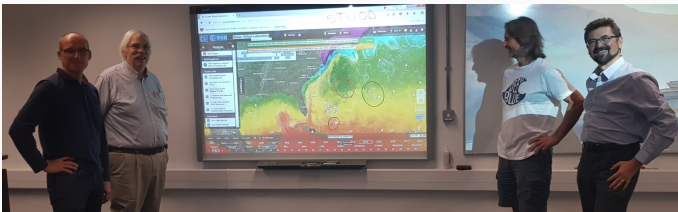
May 23, 2022

Joint work with Etienne Mémin¹, Bertrand Chapron² and Noé Lahaye¹

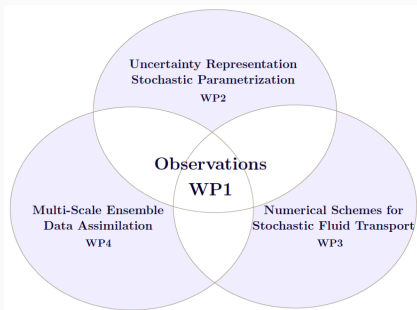
¹ ODYSSEY - Inria Rennes France

² LOPS - Ifremer Brest France

Stochastic Transport in Upper Ocean Dynamics (STUOD)



<https://www.imperial.ac.uk/ocean-dynamics-synergy/>



“Our approach accounts for transport on scales that are currently unresolvable in computer simulations, yet are observable by satellites, drifters and floats.”

Methods: SALT [Holm, 2015] or LU [Mémin, 2014]

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- Flow under location uncertainty (LU)

$$d\mathbf{X}_t = \underbrace{\mathbf{u}(\mathbf{X}_t, t) dt}_{\text{resolved}} + \underbrace{\sum_m \xi_m(\mathbf{X}_t, t) dB_t^m}_{\text{unresolved}}$$

References: [Bauer et al., 2020a, Li, 2021]

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- Stochastic transport of tracer

$$\mathbb{D}_t \Theta := d_t \Theta + \underbrace{\left(\mathbf{u}^* dt + \sum_m \xi_m dB_t^m \right) \cdot \nabla \Theta}_{\text{backscattering}} - \underbrace{\frac{1}{2} \nabla \cdot \left(\sum_m \xi_m \xi_m^T \nabla \Theta \right)}_{\text{eddy diffusion}} dt = 0$$

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- Pathwise conservation of moments

$$\mathbb{D}_t \Theta^p = 0, \quad d_t \int_{\Omega} \Theta^p dx = 0$$

References: [Bauer et al., 2020a, Li, 2021]

Application to Q-GCM [Hogg et al., 2003]

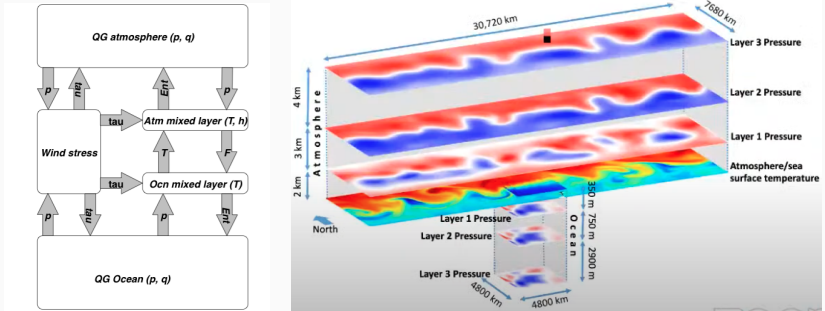


Figure 1: Model illustration from <http://www.q-gcm.org>

- Idealized midlatitude coupled model emphasizing ocean dynamics

Application to Q-GCM [Hogg et al., 2003]

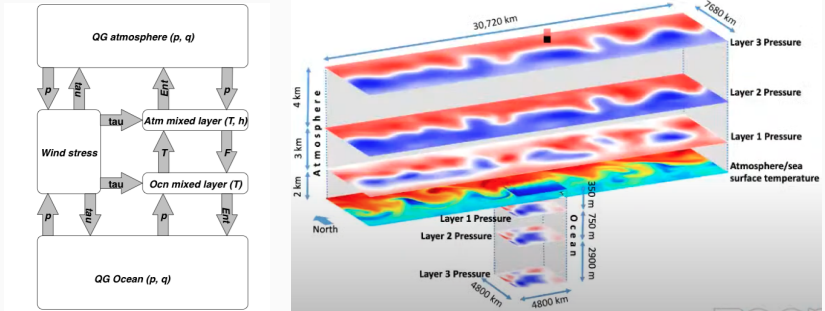


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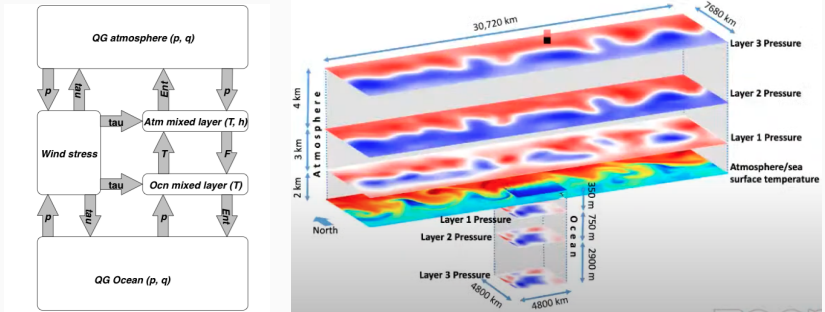


Figure 1: Model illustration from <http://www.q-gcm.org>

- Idealized midlatitude coupled model emphasizing ocean dynamics
- Classical Ekman model with wind-current-dependent stresses
- Our applications: stochastic transport of PV and SST for both ocean and atmosphere

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- Code available on:
https://github.com/matlong/qgcm_lu
https://github.com/louity/qgm_pytorch

Numerical results

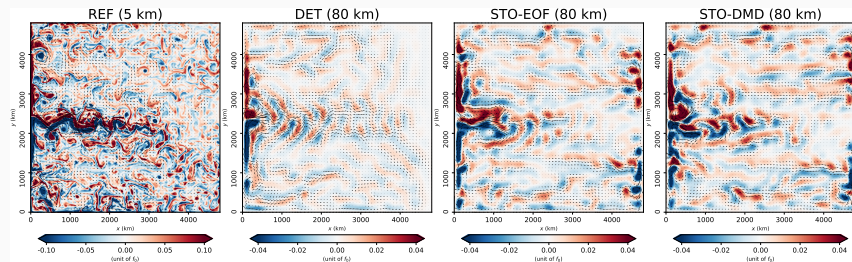


Figure 2: Snapshots of ocean upper layer relative vorticity.

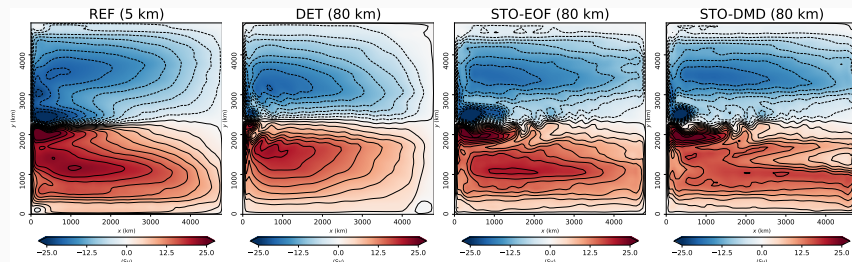


Figure 3: 40-years averages of ocean upper layer streamfunction.

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[Bachman, 2019, Jansen et al., 2019]

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- Ensemble forecasting and data assimilation

Thank you very much!

Questions?



Bachman, S. D. (2019).

The GM+E closure: A framework for coupling backscatter with the Gent and McWilliams parameterization.

Ocean Modelling, 136:85–106.



Bauer, W., Chandramouli, P., Chapron, B., Li, L., and Mémin, E. (2020a).

Deciphering the role of small-scale inhomogeneity on geophysical flow structuration: a stochastic approach.

Journal of Physical Oceanography, 50(4):983–1003.



Bauer, W., Chandramouli, P., Li, L., and Mémin, E. (2020b).

Stochastic representation of mesoscale eddy effects in coarse-resolution barotropic models.

Ocean Modelling, 151:101646.



Brecht, R., Li, L., Bauer, W., and Mémin, E. (2021).

Rotating shallow water flow under location uncertainty with a structure-preserving discretization.

Journal of Advances in Modeling Earth Systems, 13.



Gaube, P., Chelton, D. B., Samelson, R. M., Schlax, M., and O'Neill, L. W. (2015).

Satellite observations of mesoscale eddy-induced Ekman pumping.

Journal of Physical Oceanography, 45:104–132.



Hogg, A. M., Dewar, W. K., Killworth, P. D., and Blundell, J. R. (2003).

A quasi-geostrophic coupled model (Q-GCM).

Monthly Weather Review, 131(10):2261–2278.



Holm, D. D. (2015).

Variational principles for stochastic fluid dynamics.

Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 471(2176):20140963.



Jansen, M. F., Adcroft, A., Khani, S., and Kong, H. (2019).

Toward an energetically consistent, resolution aware parameterization of ocean mesoscale eddies.

Journal of Advances in Modeling Earth Systems, 11(8):2844–2860.



Lapeyre, G. and Klein, P. (2006).

Dynamics of the upper oceanic layers in terms of surface quasigeostrophy theory.

Journal of Physical Oceanography, 36:165–176.



Li, L. (2021).

Stochastic modeling and numerical simulation of ocean dynamics.

Theses, Université Rennes 1.



Li, L., Mémin, E., and Tissot, G. (2022).

Stochastic parameterization with dynamic mode decomposition.

<https://hal.archives-ouvertes.fr/hal-03597550>.



Mémin, E. (2014).

Fluid flow dynamics under location uncertainty.

Geophysical & Astrophysical Fluid Dynamics, 108(2):119–146.